INNOVATIVE DRAFT-VARYING HYBRID FLOATING BREAKWATER-WAVE ENERGY CONVERTER: AN EXPERIMENTAL STUDY

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INTRODUCTION

The marine environment is increasingly recognized as a prime candidate for driving economic growth in the energy sector, thanks to its abundant natural resources such as waves, wind, and solar energy (Jonson et al., 2018). The National Research Council of Italy has proposed a novel concept of an energy hub for the Mediterranean Sea, envisioning the assembly of various devices harnessing marine renewables. The successful realization of this ambitious floating energy archipelago heavily relies on establishing a sheltered sea area with minimized wave heights.

To meet this requirement, a specially designed floating breakwater module has been developed to encircle the energy hub, potentially arranged in multiple rows. Additionally, there is an intriguing exploration of using this floating module for both its traditional dissipative function and as a wave energy converter. This dual-purpose implementation poses a significant technical challenge, involving the optimization of both functionalities through adjustments in the module's draft (Russo et al., 2021; Russo et al., 2023).

In comparison to existing hybrid floating breakwater-Wave Energy Converters (Zhao et al., 2019), the novelty of this device lies in the optimization of both functions by varying its draft. During extremely rough seas, the hybrid module should function solely as a passive breakwater, absorbing incoming waves and safeguarding the equipment within the archipelago. Conversely, in more frequent mild sea states, the floating module should operate as a WEC, enhancing the archipelago's energy output. The generated energy can be stored and utilized to support the development of new productive activities, including aquaculture, the resource-intensive process of seawater desalination, and the production of environmentally friendly fuels like methanol or hydrogen.

This study presents results obtained from experimental tests conducted on a single 1:10 and several 1:40 Froude-scaled models. The dynamic behavior of the hybrid device is assessed in terms of response amplitude operators, while wave attenuation performances are evaluated by the transmission coefficient. Both results determine the effectiveness of the dual functionality

EXPERIMENTAL SET-UP

Experimental tests were conducted in Spring 2022 at the Maritime Hydraulic Laboratory of the Department of Engineering at the University of Campania “Luigi Vanvitelli,” which houses a 12.5m x 15.7m wave tank with an average depth of 1.6m. The device underwent testing at two different scales: a 1:10 Froude scale to accurately model the WEC behavior under mild and more frequent sea states, and a 1:40 Froude scale to simulate the breakwater behavior when exposed to extreme sea states.

Since the 1:10 model was specifically designed to assess WEC conditions, it was crucial to determine its dynamics, which, when compared to that of the waves, provides information on its effectiveness. This is particularly relevant when the wave and the device are close to resonance, allowing for the optimal extraction of energy. Additionally, the measurement of the transmission coefficient was preferred. Three draft values were investigated at full scale: D1=1.25m, D2=2.5m, and D3=3.5m.

For the 1:40 scale model, a fourth draft value, D4=4.75m, was examined. However, as a single module proved incapable of adequately attenuating waves, it was solely utilized to determine the dynamics of the scaled device. Instead, two rows of staggered modules were tested to evaluate the transmission coefficient.

Regular and irregular wave tests were conducted for each draft value, as shown in Figure 1. The tests included three values of steepness (ka=0.075, 0.15, and 0.2) and were characterized by wave heights ranging from H=0.01m to H=0.15m.

Figure 1 – A single module (upper) and several modules (lower) under regular waves.

RESULTS

The dynamic response was assessed through the definition of the response amplitude operator of motion, acceleration, and tension in mooring lines, while attenuation performances were evaluated by means of the transmission coefficient.

Concerning the individual 1:10 module tested in three different setups, the assessment of heave and roll response amplitude operators revealed a peak response close to the respective natural periods of the structure. The transmission coefficient exhibited a strong dependence on the structure's natural period, increasing as it approached the roll and heave resonance periods, reaching its maximum values of 0.87 for D1, 0.92 for D2, and 0.63 for D3. Apart from the values corresponding to the resonance periods, transmission coefficients for the 1:10 model were relatively low. However, considering that the maximum relative wavelength λ/Bw is approximately 20 (i.e., λ ≃ 6m), this is not surprising, as it is well-known that floating breakwaters operate effectively in short waves.

To thoroughly assess the module's performance in extreme conditions, multiple 1:40 models arranged in two staggered rows, including the fourth draft value D4, were tested. The transmission coefficient exhibited a linear range, varying from 0.66 to 0.85 for relative wavelengths ranging from 10 to 53, in the case of lower steepness (ka=0.075). As the steepness increased, KT values decreased from 0.51 to 0.63 within the same relative wavelength range.

Examining the module's feasibility to function alternately as a floating breakwater or a wave energy converter, with a focus on the influence of draft, was finally investigated by comparing the roll response in the same irregular wave test for the four draft values– the first three on a 1:10 model and the last on a 1:40 model. Results revealed that the interaction was maximum in D2 condition (indicating WEC function) and minimum in D4 condition (indicating breakwater function), as shown in Figure 2. In full scale, the analyzed wave condition is representative of a mild sea state for the Mediterranean Sea in the case of the 1:10 model (λ ≃ 40m), confirming the WEC functioning, especially for D2. For the 1:40 model, it represents an extreme sea state, confirming breakwater functioning in long waves (λ ≃ 160m). In general, the module's behavior can be defined for two functional ranges: for λ up to 40m, it operates as a WEC, and for higher λ values (at least up to 160m), it could increase its draft and operate as a breakwater.

CONCLUSION

This study presents the outcomes of an experimental campaign involving an innovative draft-varying hybrid floating breakwater-wave energy converter, specifically designed for the Mediterranean Sea. Two scales of the model were examined: a 1:10 scale to assess the WEC behavior of the device and a 1:40 scale to evaluate its attenuation performances. The obtained results indicate that, depending on its draft, which is adjusted according to sea conditions, the module can effectively fulfill both functionalities. This confirms its potential in protecting multi-use offshore platforms, reducing wave loads on each component, and supplying electricity to the platform by converting wave energy.

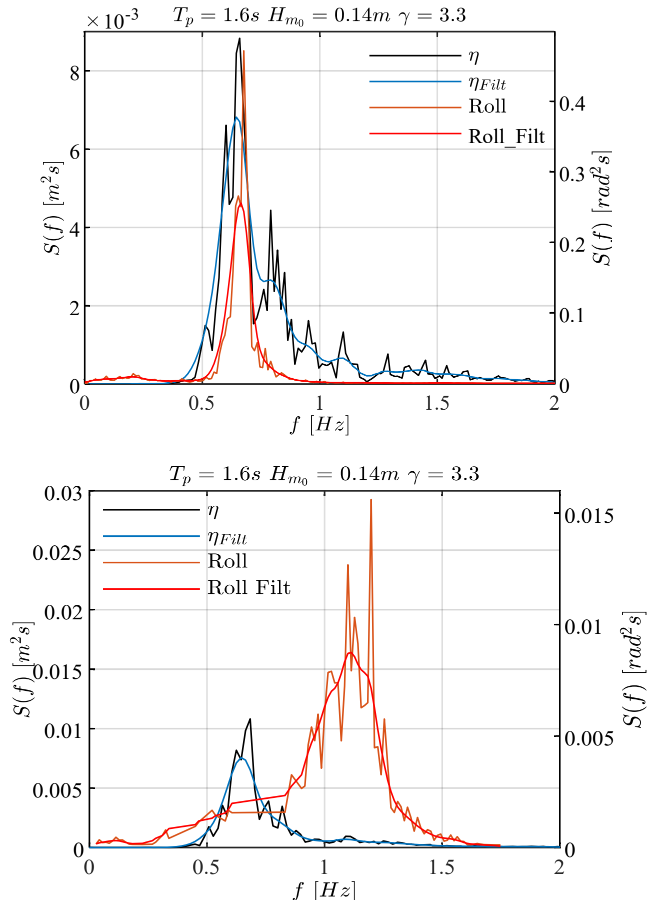

Figure 2 - Wave-Structure interaction under Irregular waves (Hm0=0.14m and Tp=1.6s), in D2 (upper) and D4(lower).

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